An aerial photograph of a modern, multi-story building with a grid-like facade. A large, dense green tree is in the foreground on the left. A person is walking on the sidewalk in the lower center. The text is overlaid on the right side of the image.

LAWRENCE LIVERMORE NATIONAL LABORATORY

Managed by the
University of California for
the Department of Energy

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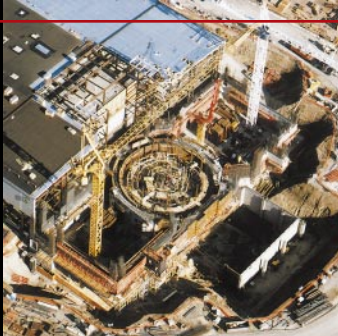
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ABOUT THE LABORATORY



Lawrence Livermore National Laboratory was founded in 1952 as a nuclear weapons laboratory. The Laboratory has been managed since its inception by the University of California, first for the Atomic Energy Commission and now for the National Nuclear Security Administration within the U.S. Department of Energy. Through its long association with the University of California, the Laboratory has been able to recruit a world-class workforce and to establish an atmosphere of intellectual freedom and innovation, both of which are essential to sustained scientific and technical excellence. As a DOE national laboratory with about 8,000 employees, Livermore has an essential and compelling core mission in national security and the capabilities to solve difficult, important problems.



C. Bruce Tarter, *Director*

IN 1999, we achieved significant successes in our research endeavors and faced major challenges both to our programs and to the way we operate. Our accomplishments make clear our role as a Department of Energy (DOE) national laboratory. We are striving for major scientific and technical advances toward DOE's goals in national security, energy resources, environmental quality, and science and technology. We are also working to meet a standard of operational excellence that should be expected of a premier national laboratory.

National security is our defining responsibility. We are a vital part of the DOE's exceptionally demanding program to maintain a safe and reliable U.S. nuclear weapons stockpile in the absence of underground nuclear testing—a supreme national interest. We are also working with DOE and other organizations to improve the nation's capabilities to stem the proliferation of weapons of mass destruction.

In many instances, our national security accomplishments depend on pushing the frontiers of science and technology. That facet of our work is demonstrated by two major DOE thrusts: the Accelerated Strategic Computing Initiative, or ASCI, and the National Ignition Facility. Both are vital to the nation's strategy for maintaining the nuclear weapons stockpile without nuclear testing, and both offer the promise of significant advances in science.

Through ASCI, we are acquiring increasingly powerful computers, which we are using to vastly improve simulations of weapons physics. And as this report highlights, high-performance scientific computing is central to all of the Laboratory's programs.

The National Ignition Facility (NIF), which will be the world's largest laser, is under construction at the Laboratory. With the successes made in component development, the technology approach for this extraordinarily challenging project is sound. However, as we informed DOE in August, the project will take longer and cost more than initially planned. We are working with DOE to address issues that were raised and revise the schedule. Work on NIF is proceeding. The Laboratory and the DOE are committed to all actions necessary to ensure the success of NIF.

Issues also arose in 1999 about security at the DOE national security laboratories. A serious responsibility, security is becoming increasingly challenging. We use more and more electronic information, and to succeed in our research, we must engage a science and technology community that has grown more international. During the year, we made numerous upgrades to improve physical and cyber security. In addition, we are taking steps to improve the safety of our work environment. Success at the Laboratory demands that we meet high standards in all areas of operations.

Our accomplishments and the progress we are making to address the issues that arose in 1999 are a credit to the dedicated employees at the Laboratory. This annual report exemplifies only some of their fine work. At Livermore, we are dedicated to ensuring national security and applying science and technology to the important problems of our time.

C. Bruce Tarter

LAWRENCE LIVERMORE

1999—News and

JANUARY

Element 114 Discovered

News broke about the discovery of element 114 by researchers from Livermore and the Joint Institute for Nuclear Research in Dubna, Russia. A long-sought experimental goal, element 114 lived 100,000 times longer than the previous new element found, element 112.



FEBRUARY

On-Site Senate Hearings

The Senate Armed Services Committee held a field hearing at Livermore about DOE's Stockpile Stewardship Program to maintain the nation's nuclear arsenal without nuclear testing. Congressional interest remained high in 1999 with news about security at the weapons laboratories, debate on the Comprehensive Nuclear Test Ban Treaty, and formation of the National Nuclear Security Administration.



MARCH

Laser Science Breakthrough

At the centennial meeting of the American Physical Society, Laboratory researchers reported that they produced antimatter and stimulated nuclear fission by focusing the world's most intense and powerful laser on a thin target. Livermore pursues many breakthrough applications in precision manufacturing and scientific research using ultrashort-pulse lasers.



JULY

Security & Safety Improvements

Laboratory Director Bruce Tarter testified before Congress about our focused efforts to tighten security at Livermore, and at year's end, we were rated "satisfactory" in overall security performance—the highest on a three-tiered rating scale. In July, we also began implementation of DOE's Integrated Safety Management System.



AUGUST

National Ignition Facility Issues

The Laboratory informed DOE that construction of the National Ignition Facility (NIF), a cornerstone of DOE's Stockpile Stewardship Program, will take longer and cost more than initially planned. However, the underlying science and technology are sound for completing this stadium-size complex with the world's most powerful laser. Secretary Richardson ordered a series of actions that is leading to a revised schedule, and the project is proceeding.



SEPTEMBER

R&D 100 Award Winners

Livermore scientists and engineers were presented with six R&D 100 Awards for outstanding achievement in R&D. Our winning technologies have applications in laser machining, communications, computer chip manufacturing, cancer therapy, and law enforcement.



NATIONAL LABORATORY

Accomplishments

APRIL

Genome Dedication

DOE Secretary Bill Richardson dedicated the Joint Genome Institute (JGI) Production Sequencing Facility in Walnut Creek, California. A "working draft" of the sequence for chromosomes 5, 16, and 19 is expected to be completed early in 2000. The JGI is made up of genome researchers from three DOE national laboratories.



MAY

Biodetector Field Trials

Our Advanced Nucleic Acid Analyzer demonstrated in field tests a high probability of detecting even a single target DNA strand in a sample. Livermore is delivering to DOE and other sponsors unique instruments that have dramatically advanced biological-agent detection.



JUNE

W87 Warhead Refurbished

Livermore's program to extend the life of the W87 ICBM warhead met the Air Force's Initial Operational Capability requirement. Earlier in the year, the Pantex plant completed production of the first Laboratory-designed refurbished W87, and a significant number have since been delivered to the Air Force.



OCTOBER

Supercomputer Dedication

The Laboratory and IBM celebrated the "coming of age" of the Blue Pacific supercomputer, capable of nearly 4 trillion operations per second. The advanced computing capabilities at Livermore, created by DOE's Accelerated Strategic Computing Initiative (ASCI), are a key component of stockpile stewardship and make possible scientific breakthroughs in many areas.



NOVEMBER

Environmental Cleanup Success

An environmental remediation technology developed at Livermore had removed 1.2 million pounds of contaminants from an original Superfund site in Visalia, California—an accomplishment that would have taken more than a thousand years using traditional methods. Great progress also continues in remediation of the Livermore site, expected to be completed almost 20 years ahead of schedule.



DECEMBER

Weapons Research Milestone

The first-ever three-dimensional simulation of a nuclear weapon primary explosion was completed using the Blue Pacific computer at Livermore. The success marks a major milestone in the Stockpile Stewardship Program. The year concluded with a visit by Secretary Richardson, when he told Laboratory employees, "The past year has been rough, but it is time to regroup and move forward with a strong focus on our mission."



NATIONAL SECURITY

Providing for National Security in a Changing World

Lawrence Livermore National Laboratory was established in 1952 to help ensure national security through the design, development, and stewardship of nuclear weapons. National security continues to be the Laboratory's defining responsibility.

The breakup of the Soviet Union brought an end to the Cold War. However, threats to international security remain, and global interests keep the United States actively engaged in world events. The U.S. is committed to halting the spread of chemical, biological, and nuclear weapons worldwide while maintaining sufficient nuclear forces to deter any adversary. The Laboratory contributes to these important endeavors.

Now a Part of the New NNSA

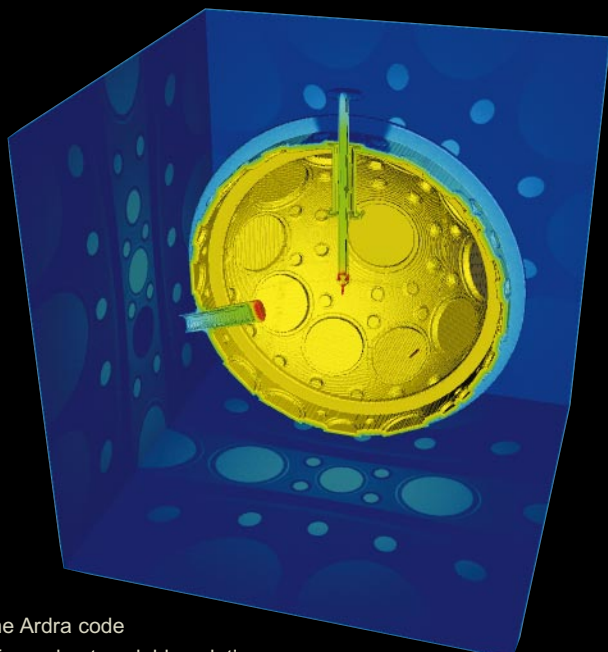
Livermore is one of three national security laboratories that are part of the new National Nuclear Security Administration (NNSA) within DOE. Created through Congressional legislation enacted in 1999, the NNSA formally starts operation in March 2000. The NNSA will bring together DOE's national security functions and give them a clear focus.

Safe and Reliable Nuclear Weapons

As one of the DOE National Nuclear Security Administration laboratories, Livermore plays a prominent role in the Stockpile Stewardship Program for maintaining the safety and reliability of the nation's nuclear weapons in the absence of nuclear testing. At the Laboratory, we are attending to the immediate needs of the stockpile by using a combination of laboratory experiments and computer simulations as a basis for performance assessments and certification. We are also acquiring more



Technicians assemble equipment used to dispose of plutonium from dismantled weapons. At Livermore's plutonium facility, we support the Stockpile Stewardship Program with basic research on the properties of plutonium so we can better understand how it ages and develop improved methods to process the material. The facility is also central to DOE's program to immobilize and dispose of excess U.S. plutonium.



The Ardra code offers robust scalable solution methods for neutron and radiation transport problems in three-dimensional geometries such as this calculation of a laser fusion target chamber.

powerful experimental and computational tools to address the more challenging issues that will arise as the nation's nuclear weapons stockpile continues to age.

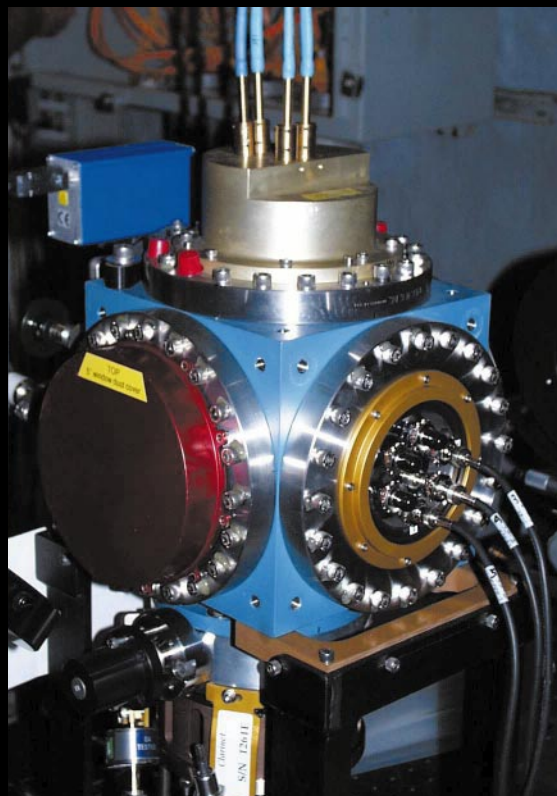
Proliferation Prevention and Arms Control

The Laboratory is addressing the increasingly serious problem of the proliferation of chemical, biological, and nuclear weapons through a wide spectrum of analysis and technology development activities. In addition, Livermore provides the

government with technical information and assistance to support the development of national policy on nuclear weapons, nonproliferation, and arms control matters.

Technology for New Military Requirements

Building on the scientific and technical capabilities needed for the Laboratory's stockpile stewardship and nonproliferation missions, Livermore develops advanced defense technologies for the Department of Defense to increase the effectiveness of U.S. military forces.



This assembly was part of the subcritical experiment Clarinet, which was successfully conducted in an underground complex at the Nevada Test Site. It was the third in a series of experiments to study plutonium properties under extreme conditions.

Stockpile Stewardship

Attending to Stockpile Needs

As a principal participant in the Department of Energy's Stockpile Stewardship Program, Livermore is committed to maintaining confidence in the safety and reliability of the U.S. nuclear weapons stockpile. The program is extraordinarily demanding because the nuclear weapons in the stockpile continue to grow older, and we are challenged to ensure their performance and refurbish them as necessary without conducting nuclear tests.

The Stockpile Stewardship Program integrates the activities of the DOE nuclear weapons complex, which includes Livermore, Los Alamos, and Sandia national laboratories as well as four production sites and the Nevada Test Site.

Certifying Stockpile Safety and Reliability


The objective of the Stockpile Stewardship Program is to provide the President of the United States with accurate assessments of the safety, reliability, and performance of each weapon system in the nation's nuclear stockpile. We provide these assessments through a formal annual certification process that relies critically on the expertise and capabilities of Livermore, Los Alamos, and Sandia national laboratories and their independent evaluations.

In 1999, the laboratories completed the technical reviews that provided the basis for the fourth certification of the stockpile for the President. Subsequently, the secretaries of Energy and Defense certified to the

President that the U.S. nuclear stockpile is safe and reliable and that no nuclear tests are needed.

Stockpile Stewardship Program "On Track"

In December 1999, a 30-Day Review of the Stockpile Stewardship Program concluded that the program's structure is "on track" and that "science-based stewardship is the right path." The review was commissioned by Secretary of Energy Bill Richardson to examine accomplishments and program structure to ensure that current and long-term needs for certifying the stockpile can be met. The specific findings of the review will help shape future decisions in the program to manage technical challenges and requirements, which will increase as the stockpile continues to age.



The technician (top) uses a solid-phase microextractor to collect samples of gases produced by organic materials in a weapon. The sample is then desorbed in the injection port (above and right) of a gas chromatograph-mass spectrometer, which identifies the compounds and measures their amounts. The analysis provides indications of material aging.



"The past year has been rough, but it is time to regroup and move forward with a strong focus on our mission," DOE Secretary Bill Richardson told Livermore employees in December. His visit followed high-level reviews of the Stockpile Stewardship Program and security improvements at the Laboratory.

Prior to the review, and with input from the laboratories and production facilities, the DOE Office of Defense Programs undertook a major shift in management strategy in response to evolving demands on the program. The revision recasts major elements of the Stockpile Stewardship Program into a set of activities that more clearly establish program goals and budget priorities and help to identify program risks if there are budget shortfalls. Integrated program activities include:

• **Directed Stockpile Work.**

These activities support the readiness of weapons and include activities to meet stockpile requirements. We have special responsibilities for the weapon systems that were designed at Livermore: the W87 and W62 ICBM warheads, the B83 bomb, and the W84 cruise missile.

• **Campaigns.** Campaigns are directed at making the scientific and technological advances necessary to assess and certify weapon performance over the long term without nuclear testing. Each of the 18 campaigns has well-defined, specific deliverables on which its research and development efforts are focused.

• **Readiness in Technical Base and Facilities.**

Readiness requires investments to be made in people, special experimental facilities, and supporting infrastructure to conduct the program today and to have in place the needed capabilities as more challenging stockpile issues arise in the future.

Refurbished Warhead Meets Requirements

In June 1999, Livermore's W87 Life Extension Program met the Air Force's Initial Operational Capability (IOC)



Now on Peacekeeper missiles, the W87 warhead/Mk21 reentry vehicle (RV) is a candidate for a single RV in the Minuteman III ICBM under the START II Treaty. Development activities to refurbish the W87 and extend its life included extreme environmental testing such as transportation and handling shocks, temperature changes, and missile launch and flight conditions.

requirement. The first refurbished unit was completed at the Pantex Plant in February 1999, and a significant number of refurbished W87 units have already been delivered. Refurbishment of the W87 ICBM warhead, the design with the most modern safety features in the stockpile, extends the lifetime of the weapon to beyond 2025. We completed all development activities, which have included flight testing, ground testing, and physics and engineering analysis. No additional nuclear

testing of the W87 is required to prove system reliability after the refurbishment. Assessment of nuclear performance is based on computer simulation, past nuclear tests, and new above-ground experiments that address specific physics issues.

Stockpile Stewardship

Modeling and Experiments

Decisions and actions about the stockpile must be grounded in experimental reality. In the past, that reality included nuclear testing. Now, we go about the business of ensuring stockpile performance using laboratory experiments and computer modeling to achieve a much more sophisticated understanding of underlying physics and engineering issues.

Understanding Plutonium

We are making significant progress in understanding plutonium, which is an extremely complicated material. To study the subtleties of this metal, we have combined advances in theoretical modeling of plutonium with the use of research tools made available through Stockpile Stewardship Program investments. We need to understand aging in

plutonium and the effect of aging-related changes on the performance of an imploding pit of a stockpiled weapon. Otherwise, we will not be able to accurately assess the lifetime of weapon pits and determine whether the nation must invest in new capabilities for plutonium operations.

One tool we use is subcritical testing at the Nevada Test Site. Livermore scientists are carrying out a series of experiments to investigate the properties of plutonium shocked and accelerated by high explosives. Matter can be ejected from the surface of materials that undergo shock. We are trying to characterize plutonium ejecta, which are thought to affect the performance of primaries in weapons. In 1999, we conducted three successful subcritical experiments: Clarinet in February and Oboe-1 and Oboe-2 in September and November.

We are using the Omega laser at the University of Rochester to conduct high-energy-density experiments while NIF is being constructed. Omega is similar to Nova in its ability to deliver energy to a target.



During the calculation of a nuclear primary explosion, 6 million megabytes of data were written in a total of 50,000 graphics files. Analyzing the generated data from the Blue Pacific supercomputer requires powerful visualization tools. The extremely high resolution and superior image quality of Livermore's Assessment Theater provide weapon scientists with detailed views of the results of complex simulations.

Unlike the previous experiments, the Oboe tests were the first to be performed inside individual confinement vessels. As a result, personnel are now allowed to enter the underground test chamber—the zero room—to retrieve films and data after the test, once the chamber is determined to be free of contamination. The use of vessels for subcritical experiments will result in significant cost reduction and improved data return. In the past, each subcritical experiment took a minimum of one year to field and rendered unusable all diagnostic equipment in the zero room.

We also will be carrying out accelerated aging tests on specially prepared plutonium samples. They include a mixture of isotopes different from that used in weapons-grade plutonium, so we will be able to accelerate the rate of self-irradiation damage, which is a key factor in aging.

3D Simulation of a Nuclear Explosion

As Secretary Richardson announced in December 1999, the first-ever three-dimensional simulation of a nuclear weapon primary explosion was completed using the Blue Pacific supercomputer at Livermore. The simulation is a major milestone in the Stockpile Stewardship Program and an important step forward in the full-system modeling of weapon performance.

Three-dimensional simulation is critically important because phenomena during a nuclear explosion—such as high-explosive detonation, hydrodynamics, and radiation transport—are not symmetric in many cases because of aging and manufacturing variations. To accurately model the interaction of these complex phenomena demands unprecedented computational capability.

The computer model that was used employs tens of millions of zones—hundreds of times more than a comparable two-dimensional simulation. The simulation ran a total of 492 computer hours and used 640,000 megabytes of memory (in contrast to tens of megabytes of memory in a typical desktop computer).

The work was completed through an intense, sustained effort that involved weapons code developers and computer support personnel at Livermore and from IBM. It required innovative three-dimensional algorithms able to represent the relevant physical processes and run efficiently on the Blue Pacific machine's parallel architecture.

Nova Ceases Operation

In July 1999, operations ceased at Livermore's Nova laser facility in order to bring online the National Ignition Facility (NIF), which will be

more than 60 times more powerful than Nova. High-energy lasers serve as experimental tools to generate data and validate simulation codes near—but not quite at—weapon-physics conditions. Until NIF operations begin, we are using the Omega laser at the University of Rochester to conduct high-energy-density experiments. Recent experiments at Omega have allowed a detailed comparison of two radiation transport models, with results that will be valuable for stockpile stewardship.

Stockpile Stewardship

Greater Capabilities to Come

The greatest challenges in stockpile stewardship lie ahead, as weapons continue to age. Program success depends on bringing into operation vastly improved scientific capabilities, which will be used by our experienced nuclear weapons designers to train and evaluate the skills of the next generation of stockpile stewards, who will rely on the new tools.

Supercomputer Comes of Age

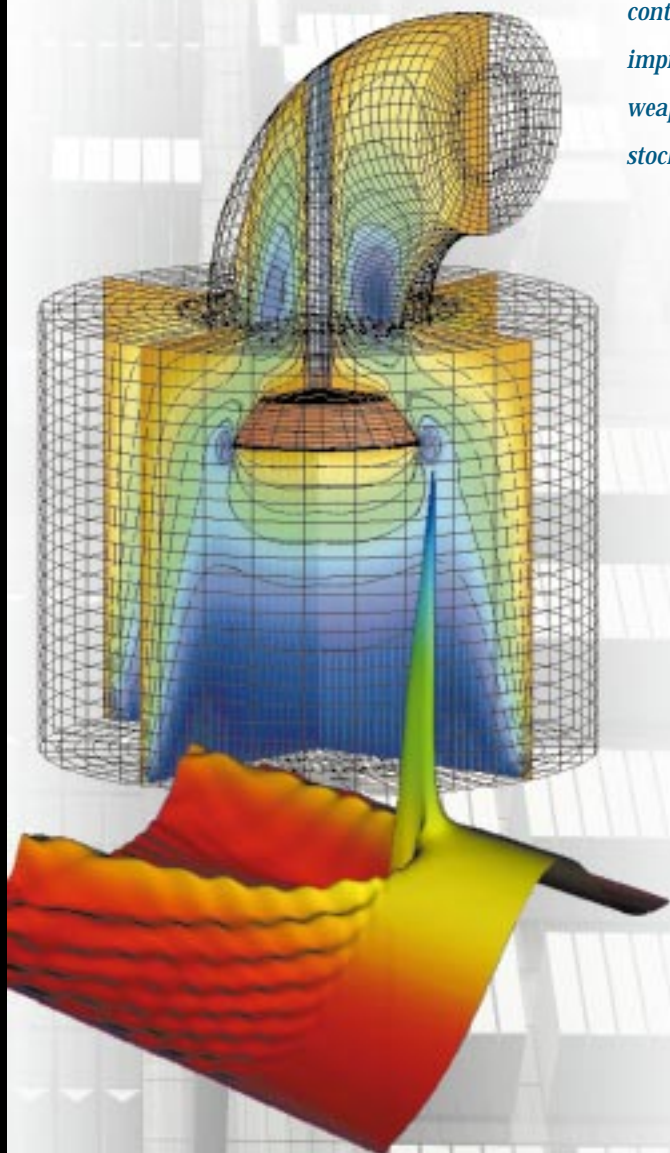
In a special ceremony on October 28, 1999, the Laboratory and IBM celebrated the "coming of age" of the Blue Pacific supercomputer with a special ceremony at Livermore. This machine, part of the Department of Energy's Accelerated Strategic Computing Initiative (ASCI), has been developed and delivered in several stages over the past three years. With all the critical elements now in place—software and code development, a functional problem-solving environment, interconnect and communications capabilities, and data storage facilities—Blue Pacific has become a mature tool for stockpile stewardship.

Created by IBM, Blue Pacific performs nearly 4 trillion operations per second, applying all of its 5,856 processors in parallel to a single computational problem. The supercomputer is 15,000 times faster than the average desktop personal

computer. In addition, the machine has over 2.6 trillion bytes (2.6 terabytes) of memory—80,000 times more than the average desktop personal computer—and could store all of the books in the Library of Congress.

The October ceremony highlighted breakthrough research calculations performed on the new machine and included a preview of Option White. Currently being built by IBM as an extension of Blue Pacific, this machine will be able to perform 10 trillion operations per second and will have three times the capacity of Blue Pacific. Option White is planned for delivery in summer 2000. It is the next step in a strategy of acquiring successively much more powerful supercomputers through ASCI.

The advanced computing capabilities at Livermore created by ASCI also offer the potential of leading to unprecedented levels of understanding in climate and weather modeling, environmental studies, the design of new materials, and many areas of physics.



Through the Accelerated Strategic Computing Initiative, Livermore is acquiring successively more powerful computers for stockpile stewardship. For DOE sponsors, we develop applications that run efficiently on the machines' massively parallel architecture. Simulations are shown of the dynamics of complex systems (top) and the interactions of intense laser light with plasma (bottom).

Pushing the NIF Construction Forward

Construction is under way at Livermore on the National Ignition Facility (NIF), a cornerstone of DOE's Stockpile Stewardship Program. This stadium-size complex will house the world's most powerful laser. With NIF, many of the fundamental processes of thermonuclear detonation will, for the first time, become accessible to laboratory study and analyses.

By firing its laser beams in unison and focusing its energy on a BB-size target for a few billionths of a second, NIF will generate the temperatures and pressures needed to conduct experiments to validate weapons-physics computer codes and address important issues of stockpile stewardship. NIF also will provide a powerful new tool for basic research into the physics of stars, high-energy plasmas, and fusion energy.

Construction of the NIF building complex will be completed in 2001 as initially planned, and installation of the laser infrastructure will be under way. We have achieved extraordinary success in many technology areas—from new production processes to make the required 150 tons of laser glass to techniques for rapid growth of extremely large crystals used for frequency conversion. The underlying



The 130-ton target chamber of the National Ignition Facility—which will house the world's most powerful laser—is shown being hoisted into place in the football-stadium-size building in June 1999.

science and technology of the project are sound. However, the project will take longer and cost more than initially planned.

In September 1999, Secretary Richardson ordered a series of actions to address the schedule and cost issues that have arisen. At the same time, we made significant changes in the Laboratory's NIF management team. The Secretary's actions included the appointment of a task force of the Secretary of Energy Advisory Board to review NIF.

The NIF Laser System Task Force concluded in its Interim Report that "... with appropriate corrective actions, a strong management team, additional funds, an extension of schedule, and recognition that NIF is, at its core, a

research and development project, the NIF laser can be completed." They added, "Several recent management changes as well as the new focus on systems engineering are encouraging."

We are committed to all actions necessary to ensure the success of NIF, which is an essential element of the Stockpile Stewardship Program. The new NIF project management team is developing a revised NIF project plan, and the project is proceeding.

Proliferation Prevention and Detection

The proliferation of nuclear, chemical, and biological weapons (collectively referred to as weapons of mass destruction, or WMD) is a growing threat to U.S. and world security. Our program in nonproliferation, arms control, and international security is tackling the problem of WMD proliferation across the entire spectrum of the threat. We are involved in activities to prevent proliferation at the source, to detect and reverse proliferant activities, and to counter WMD terrorism.

Securing Russian Nuclear Materials

Through the DOE Materials Protection, Control, and Accounting (MPC&A) Program, we are working with Russia to secure weapons-usable nuclear materials at the sites that store, process, or use those materials. For example, Livermore leads the MPC&A team that is working with the Russian Navy and Icebreaker Fleet to improve the security of fresh fuel for these nuclear-powered vessels. Upgrades for two refueling ships were commissioned in September 1999. The upgrades included covers for the nuclear fuel storage racks that can be removed only with special tools and sensors and closed-circuit TV to monitor the storage area and nearby corridors. The excellent working relationship among the Russian Navy, the

subcontractor and system integrator (the Kurchatov Institute), and the highly trained team of DOE and national laboratory personnel is facilitating efficient problem solving and system implementation.

We lead the joint U.S.-Russian plutonium disposition activities to stabilize, immobilize, and geologically dispose of excess plutonium from Russian weapons. Industrial-scale immobilization of weapons-plutonium-containing materials is planned at one or more of the three plutonium processing sites in Russia by 2004. Livermore activities focus on supporting the industrial sites' plutonium immobilization requirements. We are developing and characterizing various immobilization waste forms for plutonium and examining the nonproliferation benefits of each.

Monitoring Improved for Nuclear Explosions

Livermore is part of a multilaboratory effort to provide the U.S. government with the R&D it needs to meet its worldwide nuclear explosion monitoring goals. Efforts are focused on seismic R&D for the

Before and after views of the nuclear fuel storage racks (left and right), showing the additional barriers to delay unauthorized access, on board a nuclear refueling ship for the Russian Icebreaker Fleet.



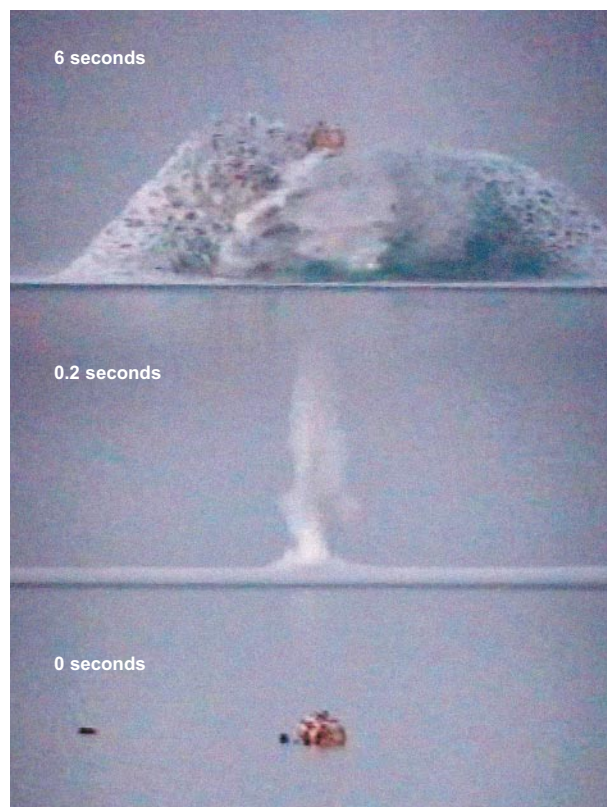
Our Center for Global Security Research sponsored a series of workshops on missile proliferation to bring together technologists and policymakers to discuss key issues. At the meeting in August 1999, the Honorable Donald H. Rumsfeld (far right), former Secretary of Defense and chair of the Rumsfeld Commission on Missile Proliferation, served as one of the panel chairs.

Middle East, North Africa, and Russia. We are working with Los Alamos and Sandia to construct a "knowledge base" that provides region-specific corrections to calculational algorithms used to locate and identify seismic events. This past year, we demonstrated that the knowledge-base concept will be able to meet U.S. monitoring goals. The locations of aftershocks from a large earthquake in the Caucasus Mountains were estimated and compared to data from published reports. Our region-specific corrections eliminated approximately 40 kilometers of bias from the estimates. Uncertainty of the aftershock locations was reduced to under 1,000 square kilometers (the limit for on-site inspections under the Comprehensive Test Ban Treaty).

We are also investigating nontraditional means of developing ground truth. From openly available satellite data, we are using pan-chromatic and synthetic aperture radar images to improve the level of ground truth in regions where physical access is difficult. For example, we are using radar data to directly identify mine collapses, which potentially are a major source of false alarms because data are similar to those of underground nuclear explosions.

New Sensors for Remote Monitoring

Chemicals associated with weapons of mass destruction (during R&D, production, testing, storage, or use) are released into the environment at levels that may be detectable by various technical means. We are developing a



An underwater 5,000-kilogram explosive was detonated in the Dead Sea in November 1999. Measurements taken at various locations in the Middle East are being used to calibrate seismic stations and improve DOE's knowledge base for the area.

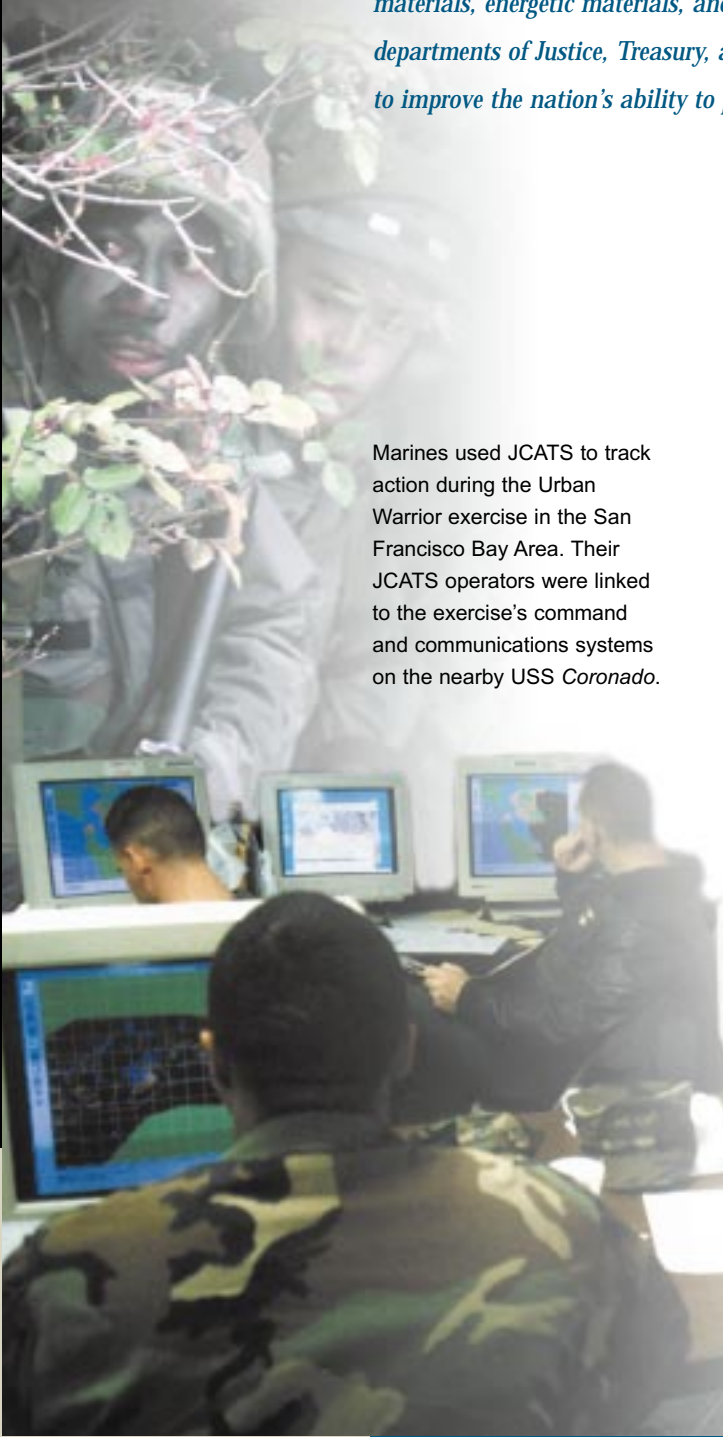
number of optical remote-sensing techniques for detecting, identifying, and quantifying signatures of the proliferation or use of weapons of mass destruction. Among these techniques are a hyperspectral infrared spectrometry system, a mid-wave infrared differential absorption lidar, and an echelle grating spectrometer (EGS).

We are exploring the use of the EGS for ballistic-missile defense applications. By looking at optical signatures following intercept of a hostile missile, we can use EGS to characterize in real time the impact debris and rapidly provide information about

enemy warheads containing chemical or biological agents. In a June 1999 field test of the concept, EGS performed flawlessly and returned useful booster plume and intercept signature information. As a result of this success, we are now funded by the Department of Defense to use EGS in the Intercept Flight Test Program to characterize intercept events.

Response to Proliferation and Other Security Threats

We work with the Department of Defense (DoD) to leverage the Laboratory's capabilities to meet a variety of national security challenges. In addition to our nonproliferation efforts, Livermore makes technological advances in such areas as missile defense, solid-state lasers, armor and antiarmor materials, energetic materials, and conflict simulation. We also work with other agencies, including the departments of Justice, Treasury, and Commerce, to respond to the 1998 Presidential Decision Directive to improve the nation's ability to prevent and mitigate attacks by terrorists using WMD.



Marines used JCATS to track action during the Urban Warrior exercise in the San Francisco Bay Area. Their JCATS operators were linked to the exercise's command and communications systems on the nearby USS *Coronado*.

Technology to Support Military Operations

In March 1999, two sophisticated computer tools developed at Livermore provided support to the Navy's Fleet Battle Experiment and the Marine Corps' Urban Warrior exercise. The Counterproliferation Analysis and Planning System (CAPS) provided real-time plume dispersal models associated with simulated chemical and biological attacks by terrorists against the 3rd Fleet and the City of Oakland. Used by U.S. combatant commands around the world, CAPS is an easy-to-use, powerful system for end-to-end process analysis of a proliferator's WMD production capabilities and for assessment of interdiction options and corresponding consequences.

The Joint Conflict and Tactical Simulation (JCATS) model supported Urban Warrior by providing a virtual

battlefield context for the Marine Corps' live exercise. The culmination of our long experience in conflict simulation, JCATS has become a standard for simulation activities used by more than 50 organizations—including U.S. military, the State Department, the Secret Service, and DOE's site-security function. JCATS allows training, planning, and tactics analysis from the campaign level (hundreds of square kilometers) to individuals fighting inside a multistory building. Version 2.0 of JCATS was delivered to the Atlantic Command's Joint WarFighting Center in October 1999.

Fast, Accurate, and Portable Biodetectors

As part of DOE's Chemical and Biological Nonproliferation Program, Livermore has developed unique instruments to dramatically advance biological agent detection capabilities. Our miniature flow cytometer uses our patented flow-stream-waveguide design, which



Applied on the left side of the petri dish, L-Gel effectively inhibits the germination of *Bacillus globigii* spores (surrogate for anthrax). Livermore's latest polymerase chain reaction (PCR) instrument (right), the HANAA, detects key biological agents.

permits the development of field-portable instruments. This past year, we demonstrated multiplex (simultaneous) detection of a suite of biological organisms and compounds (bacteria, bacterial spore, protein, and virus) using flow cytometry.

Two optimized polymerase chain reaction (PCR) instruments—the Advanced Nucleic Acid Analyzer (ANAA) and, most recently, the Handheld ANAA (HANAA)—have demonstrated a high probability of detecting even a single target DNA strand in a sample. Both instruments can detect key biological agents in 7 minutes, a breakthrough made possible through extreme miniaturization of the thermal cycling chamber. Versions of the ANAA have been delivered to the Naval Medical Research Center and the U.S. Army Medical

Research Institute of Infectious Diseases. The HANAA was delivered to its first users in December 1999. Each generation of our PCR instrumentation has been smaller, lighter, faster, and cheaper than the previous instrument.

Improved Chem/Bio Decontamination

Civilian first-responders have limited methods of chemical or biological decontamination—soap and water or bleach. Through DOE's Chemical and Biological Nonproliferation Program, we are developing a decontamination reagent that is effective against both chemical and biological agents, results in nontoxic byproducts, and is easy to use.

Livermore's L-Gel system is a fumed amorphous silica gel based on the commercial oxidizer oxone (with peroxy-monosulfate as the active

ingredient). L-Gel is noncorrosive and can be applied using a commercially available paint sprayer. It clings to walls and ceilings and does not harm carpets or painted surfaces. Laboratory and field tests over the past two years have demonstrated that L-Gel is effective on various materials found in a civilian setting against all classes of chemical warfare agents, sulfur mustard, all biological surrogates, and live vaccine strains.

Developing Lasers for DoD

In support of the Army's Space and Missile Defense Command, the Laboratory is working with industrial partners to develop a 100-kilowatt (average power) solid-state laser to be deployed on a mobile battlefield platform. Such high-power laser systems are leading candidates for an enhanced air-defense

capability. In 1999, we developed 1.5- and 10-kilowatt prototype lasers and tested their effectiveness in damaging selected materials. We plan to deliver the 10-kilowatt prototype to the High-Energy Strategic Test Facility (HELSTF) at White Sands Missile Range in 2001.

NATIONAL NEEDS

Meeting Enduring National Needs

As a national laboratory with state-of-the-art research facilities and capabilities, Livermore can respond to a broad range of important national needs. Application of the Laboratory's special skills to diverse problems leads to cross-fertilization of ideas and helps to sustain the multidisciplinary base needed for national security work. We have wide-ranging capabilities in applied science and technology, many specialized research facilities, and unique expertise in selected areas.

Livermore emphasizes projects for which research and development can lead to dramatic benefits for the nation. We seek challenges with the potential for high-payoff results, which means our work often entails significant scientific and technical risk.

Our special focus is on the critical, enduring missions of the Department of Energy and program areas that reinforce our national security work.

Energy Security and Environmental Management

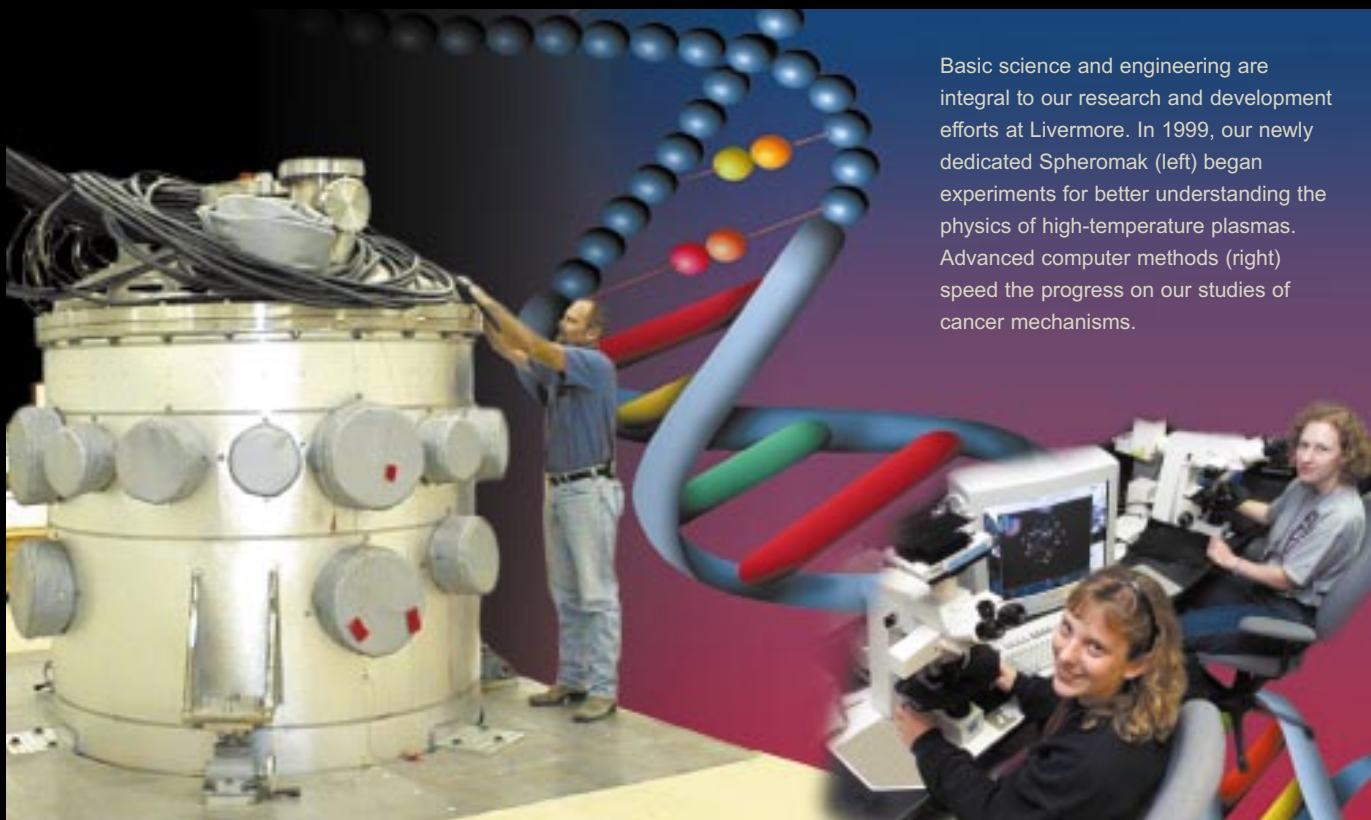
Livermore's energy and environmental programs contribute to providing the scientific and technological basis for secure, sustainable, and clean energy resources for the U.S. and to reducing environmental risks. Significant technological advances as well as broad cooperation among institutions will be required for reaching these goals. Our efforts focus on three critical

areas in which the Laboratory can make a significant difference.

Nuclear materials management is an enduring mission of DOE because it will be responsible for a vast array of nuclear materials for generations to come. We are a key contributor to nuclear materials management through various activities at the Laboratory.

Carbon management is another focus of our research because of the world's

Our tritium spectrometer is the first instrument of its kind. Considerably smaller than our large accelerator mass spectrometry (AMS) system, this new tool is advancing biological and environmental research. It enables experiments with compounds that are not amenable to carbon-14 labeling or that would require large samples and long counting times using AMS. It also can be used with carbon-14 AMS for low-level double-labeling experiments.



Basic science and engineering are integral to our research and development efforts at Livermore. In 1999, our newly dedicated Spheromak (left) began experiments for better understanding the physics of high-temperature plasmas. Advanced computer methods (right) speed the progress on our studies of cancer mechanisms.

growing demands for energy and the historically very high atmospheric concentration of greenhouse gases. We are pursuing technologies for energy generation and usage in areas where the Laboratory has special expertise. Through efforts such as our significant contributions to global climate modeling, we are also developing a better understanding of the environmental consequences of energy generation and usage that drive technology selection and implementation.

In addition, we are developing technologies to characterize and remediate contaminated groundwater faster and more cost efficiently than previously possible. We have available extremely

sensitive techniques for determining the mutagenic and carcinogenic potency of chemical pollutants.

Bioscience and Biotechnology

The Laboratory's research advances human health through efforts in genomics, disease susceptibility and prevention, and improved health care and medical biotechnology. Research activities in biology, biotechnology, and health care fit well in a technology-rich, multidisciplinary, broad-based national laboratory. A cross-fertilization of ideas and talents provides our bioscientists access to

the latest technologies in physical sciences and engineering. Conversely, bioscientists at Livermore make significant contributions to national security activities and other major programs at the Laboratory.

Fundamental Science and Applied Technology

We pursue initiatives that have the potential for major advances and reinforce research areas that are strong at the Laboratory. A variety of projects, sponsored by DOE's Office of Science or other customers, takes advantage of the unique research capabilities and facilities present at Livermore. Other work,

supported by Laboratory Directed Research and Development funding, extends the Laboratory's capabilities in anticipation of new mission requirements.

Breakthroughs in *Energy Security and Environmental Management*

Livermore's activities in energy and environmental science support DOE priorities, which include enhancing the nation's energy security, developing and making available clean energy, cleaning up former nuclear weapon sites, and finding a more effective and timely approach to nuclear waste disposal.

Our researchers are testing more than 20,000 specimens of candidate materials for packaging the waste in the proposed Yucca Mountain nuclear waste storage facility (below). Tests on samples, such as the one above at Livermore, help determine the materials' resistance to stress corrosion cracking.

Waste Storage for the Millennia

Yucca Mountain, at the Nevada Test Site, is the nation's candidate site for a high-level nuclear waste repository. The Laboratory is helping DOE to address some of the major scientific challenges in nuclear waste storage. We have been testing the materials for making waste storage containers to be buried in underground tunnels and researching the site's geology to accurately predict how the heat from buried nuclear wastes would affect the areas nearby. In particular, scientists need to know if geologic responses

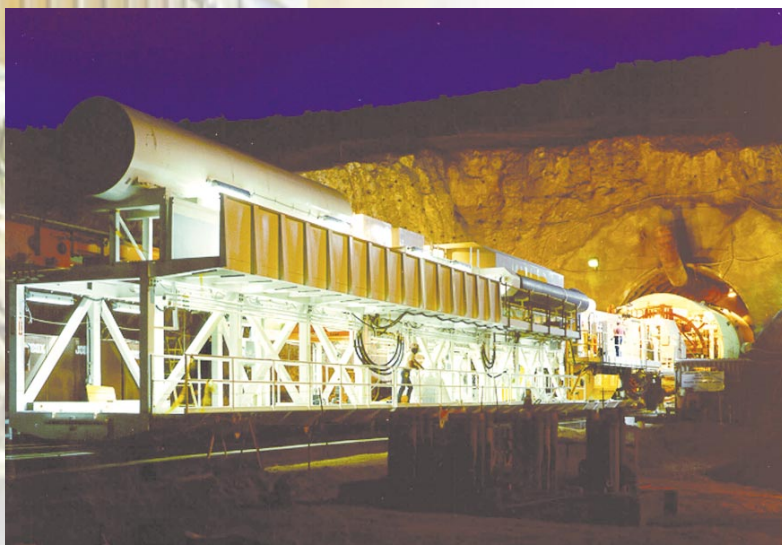
over thousands of years could cause the waste packages to corrode and spread radioactivity.

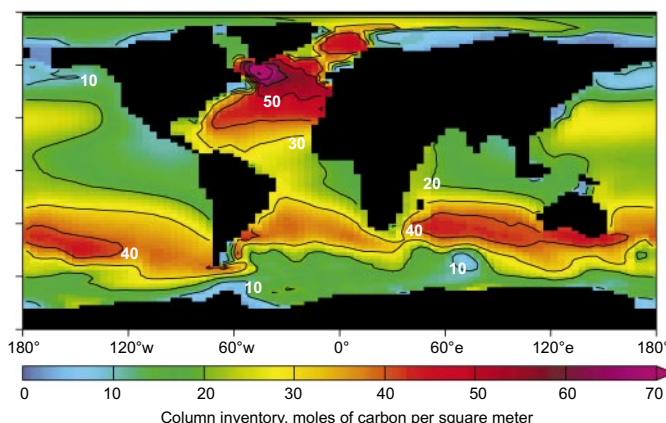
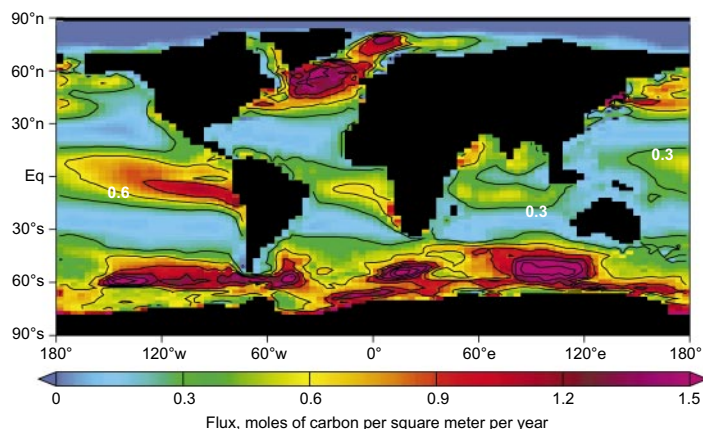
In 1999, we made major upgrades to NUFT, a code we developed for flow and transport, to model in unprecedented detail the likely evolution of the geochemistry and hydrology of the repository. The code now accounts for how chemical reactions modify rock fractures and pores and links the reactions to equations that describe the transport of heat and water. Preliminary results show that the code is a valuable tool for tracking the interplay of water, heat, carbon dioxide, and chemical reactions within the repository's naturally occurring fractured rock.

The complex code takes advantage of supercomputers designed for DOE's Accelerated Strategic Computing Initiative to solve formerly intractable scientific problems.

Carbon Dioxide Absorbed near Antarctica

When computer models first predicted what happens to carbon dioxide added to the atmosphere by humans, the





The cold water of the Southern Ocean soaks up carbon dioxide, similar to the way soft drinks absorb it (purple areas, left image). However, simulations show that the carbon dioxide does not stay there. The cold water moves north and sinks, and the carbon dioxide ends up in the subtropical Antarctic Convergence Zone (red areas, right image).

models showed that much of it was sponged up from the atmosphere and stored in the cold Southern Ocean surrounding Antarctica. But when the water was tested, no massive stockpile of carbon dioxide had accumulated.

With funding support from DOE and the National Aeronautics and Space Administration, Livermore researchers, who are part of a newly founded DOE Center for Research on Ocean Carbon Sequestration, found an explanation. Their results, published in the January 28, 2000, issue of *Science*, show that the cold water travels north and sinks into the deep subtropical ocean. Further modeling will be required to understand the net effect of global warming on sequestration of carbon dioxide in the Southern Ocean. A warmer ocean is less able to take carbon dioxide out of the air and store it, but an increased number of microscopic plants that use carbon dioxide could compensate.

Visalia Cleanup Continues Good Work

Using environmental remediation technologies developed at Livermore, a licensed industrial partner is cleaning up Southern California Edison Company's pole yard in Visalia, an original Superfund site. By November 1999, the hydrocarbons removed from the Visalia site totaled 1.2 million pounds. Dynamic underground stripping and hydrous pyrolysis/oxidation removed or destroyed in place an amount of contaminants that would have required more than a thousand years with traditional pump-and-treat cleanup, the kind used at the site since 1975.

New Twist on Ball Bearings

A Livermore inventor came up with a new type of bearing—a passive magnet bearing—that may last longer than ball bearings or other magnetic alternatives, such as

long-running, low-maintenance machines located in remote places such as space.

A mechanical bearing stabilizes the rotor until it has reached a transition speed between a few hundred and few thousand revolutions per minute. Then the repulsion force of the magnetic bearing causes the rotor to levitate and center itself, resulting in lower energy and maintenance costs by eliminating friction. For the invention, Richard Post, a lifelong researcher in energy and transportation, was presented the Design and Engineering Award for 2000 by *Popular Mechanics*.

Fuel Cell Breakthrough

Livermore developed a solid oxide fuel cell (SOFC) with world-record power density. Using a proprietary (U.S. patent pending) low-cost manufacturing technology and cell design, we have obtained power densities for single cells as high as 1.4 watts per square centimeter at 800°C. The very high efficiency of SOFCs—up to 70 percent—

enables chemical energy to be converted into electricity with much less greenhouse gas emission compared to other power sources. Because our results were obtained using a symmetrical planar cell design, it should be possible to assemble fuel-cell stacks having similar power densities and much higher total power output. The Laboratory is looking to license the technology.

Advancing Bioscience to Improve Human Health

Working with academia, industry, and government, we leverage the Laboratory's capabilities in the physical and engineering sciences to conduct research of national importance in biosciences and biotechnology. Livermore pursues technical innovations in genomics, disease susceptibility identification, and health care.

DOE and NIH Celebrate One Billion Base Pairs

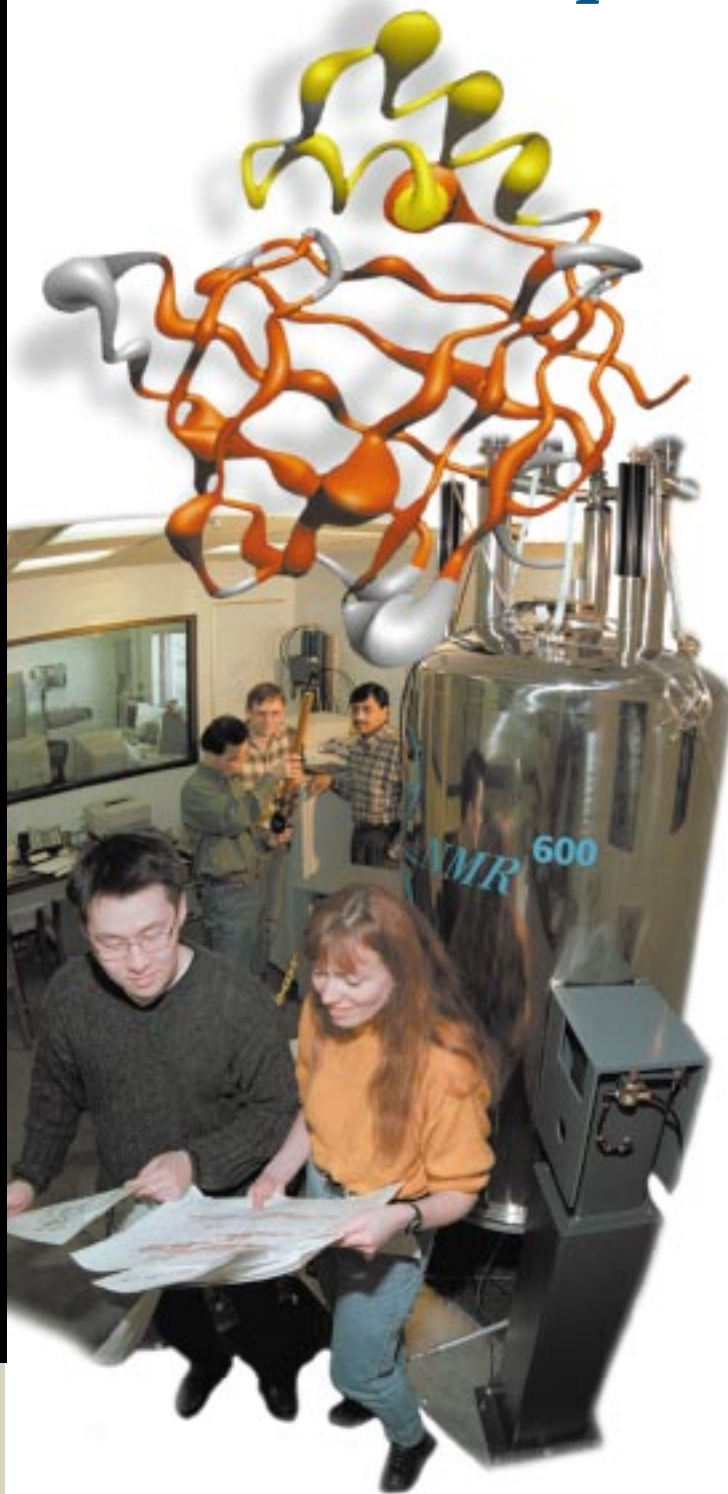
Livermore staff from the DOE Joint Genome Institute (JGI) joined in the Billion Base Pair Celebration on November 23, 1999. The event, sponsored by the National Institutes of Health and DOE, recognized the completion and deposition into GenBank of the DNA sequence for one billion base pairs of the human genome—approximately one-third of the total DNA of a human. Part of the international Human Genome Project, the JGI is made up of researchers from Lawrence Berkeley, Lawrence Livermore, and Los Alamos national laboratories.

In April 1999, DOE Secretary Bill Richardson dedicated the JGI's Production Sequencing Facility in Walnut Creek, California. That facility's capacity has since tripled with additional new sequencers, enabling the completion of a "working draft" of the sequence for chromosomes 5, 16, and 19 in early 2000.

Measuring Single DNA Molecule Interactions

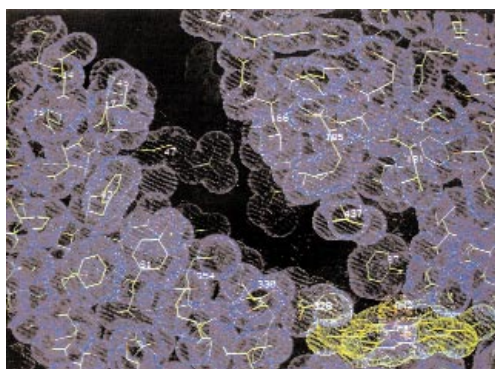
Livermore scientists have discovered more about a key step in fertility. Reported in the October 1, 1999, issue of *Science*, the analyses show the changes in the structure of a single molecule of DNA due to the binding of protamine, a small protein. Protamine has the ability to serve as a master switch, turning off all the genes in the developing sperm cell. When the sperm fertilizes an egg, the protamines are removed from the sperm's DNA, and its genes are turned back on.

In the studies, an infrared laser was used to trap and manipulate micrometer-size polystyrene spheres that were attached to the ends of DNA molecules in a specially designed dual-port flow cell. This system allowed individual DNA molecules to be moved between flow streams with and without protamine. Images of the DNA molecule's interaction with protamine were collected in real time on videotape, and the process of binding and unbinding was analyzed using successive, digitally captured images.



In Livermore's magnetic resonance laboratory, researchers collect data on the motions of the atoms in a molecular model such as a fatty-acid binding protein (above).

With its chromosomal defect in an unknown gene, this rotund mouse in the hands of a Livermore researcher is a valuable model for tracing obesity. Generations of mice, because of their genetic similarity to humans, have provided stable background for testing all but 15 percent of the genes in both species.



Measuring diffraction from x rays that are scattered by a crystallized molecule, structural biology researchers work to achieve the highest possible resolution. Data are input to advanced computational models that determine the molecule's structure.

Structural Research Strengthened

Through experimental and computational efforts, Livermore researchers are making headway on a significant bioscience challenge—determining the three-dimensional structure of proteins. Understanding the structure of proteins and how they function is essential to understanding how biological systems work. Our structural biology efforts are furthering our work on DNA damage and repair processes as well as projects to develop antidotes, detection systems, and countermeasures to biological warfare agents for minimizing the threat of exposure to them.

One area of focus is the tetanus toxin. In 1998, Livermore scientists determined the structure of the

binding domain of the tetanus toxin. This past year, Laboratory researchers looked at 250,000 compounds, predicted 30 that might bind to the toxin protein, and identified seven new molecules that can bind to it. Armed with that data, a pharmaceutical company can develop an inhibitor drug specific to the tetanus toxin.

To support these research efforts, we have established laboratories for x-ray crystallography and nuclear magnetic resonance spectroscopy, the standard experimental methods for obtaining high-resolution, three-dimensional data about individual molecules. Our experimental structural biology work is complemented by computational efforts in molecular modeling and protein structure prediction. Livermore's accomplishments include ever-growing numbers

of structure predictions. In addition, the Laboratory sponsors biannual conferences in which researchers from around the world test their abilities to predict correct protein structures.

Smoking Effects on Newborns

With a grant from the California Tobacco-Related Disease Research Program, Livermore researchers are studying the effects of smoking on newborns. In particular, they want to know whether babies born to mothers who smoked during pregnancy have more chromosome damage than babies born to nonsmokers. Their preliminary data suggests that babies born to mothers who smoked during pregnancy had twice as much

chromosome damage as babies whose mothers did not smoke during pregnancy.

The team will study blood samples taken from 300 mothers and from the fetal side of the placentas of their newborn babies. This research grows out of the team's earlier investigation of the theory that as people age, the amount of damage to their chromosomes increases. The team also will study whether some mothers or newborns are more susceptible to chromosome damage. The answer to this question may tell us whether some people are at greater-than-average risk of getting cancer as a result of tobacco exposure.

Breakthroughs in Science and Technology

The pursuit of fundamental science and the advance of applied technology go hand in hand at Livermore. State-of-the-art technology is used to increase our understanding of science in areas pertinent to the Laboratory's major missions. Conversely, Livermore's scientific advances have important spin-off applications and help to achieve program goals.

Best-Ever Images of Neptune and Titan

In 1999, the best-ever Earth-based images of Neptune and Titan, Saturn's largest moon, were taken by a Livermore-led team of scientists using the W. M. Keck II telescope in Hawaii. Keck's infrared detectors penetrated into the deep layers of Neptune's roiling atmosphere. The images show giant Neptunian storms driven by prevailing winds of 600 miles per hour. The pictures of Titan reveal features that could be frozen landmasses separated by hydrocarbon seas and lakes. These images will help researchers determine beforehand where to land the Huygens probe from the Cassini spacecraft, which is expected in 2004.

The images were taken with the newly installed adaptive optics system, which Livermore researchers helped to develop and install. In adaptive optics, mirror adjustments are used to remove Earth's atmospheric turbulence from the telescope's images, producing unprecedented clarity.

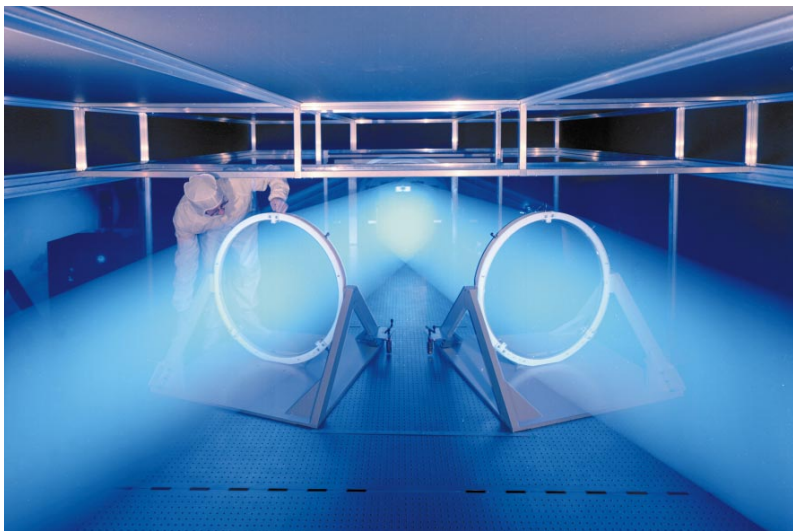
Ultrashort-Pulse Lasers Generate Antimatter

Laboratory researchers and their collaborators used the world's most intense and powerful laser to generate a short-lived fireball of energy that produced antimatter and stimulated nuclear fission. These exciting results were reported to the centennial meeting of the American Physical Society in March 1999.

The work opens the door to the world of photonuclear physics. Research that once was the province of huge particle accelerators can now be approached through high-energy laser-matter interactions. Building on Livermore's groundbreaking work, future researchers may be able to create nearly instantaneous, detailed images of nuclear and atomic structures—and possibly even proteins. They may also be able to create and study matter-antimatter plasmas like those near neutron stars and black holes.

The experiments were performed using Livermore's Petawatt laser, which ceased operation with the shutdown of Nova in July 1999. The laser's

In an image taken with the Keck II telescope, a prominent storm system can be seen on the lower right of Neptune's disk, and haze is present over the north polar regions (top). Titan (bottom), Saturn's largest moon, exhibits dark surface features in the northern hemisphere that may be lakes or seas of liquid hydrocarbons.



Livermore has unique capabilities to fabricate large diffraction gratings, which we use to stretch and later recompress petawatt-level laser pulses by a factor of 25,000 so that optical components are not damaged.

petawatt of power—a million billion watts, or more than 1,200 times the entire electrical generating capacity of the U.S.—was produced in pulses less than a trillionth of a second long.

Ultrashort-pulse lasers on a smaller scale are finding breakthrough applications in precision manufacturing and scientific research. For example, using an ultrashort-pulse laser compact enough to fit on a large table, another Livermore-led team of scientists created tiny fusion explosions. The continuing research is aimed at increasing the number of fusion neutrons produced. The highly energetic neutrons can

be used as probes, much like x rays, to investigate defects in materials ranging from metals to human tissue.

New “Stable” Super-Heavy Element Created

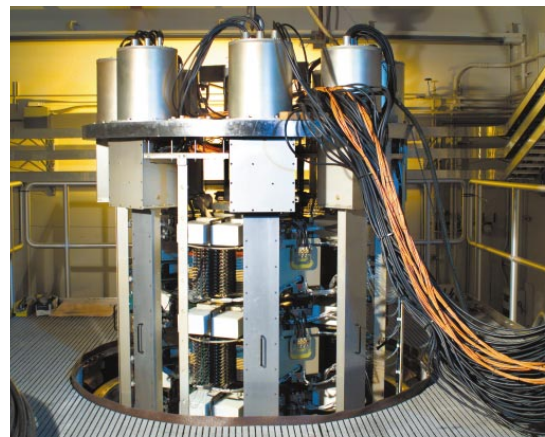
Researchers from Livermore and the Joint Institute for Nuclear Research in Dubna, Russia, discovered element 114. With 114 protons and 175 neutrons in its nucleus, the super-heavy element existed for 30 seconds before decaying into lighter elements. Element 114 lies in a predicted island of nuclear stability, a long-sought experimental goal, and lived 100,000 times longer than the previous new element found, element 112.

In a 40-day-long experiment that generated just one atom of element 114, the scientists

used a heavy-ion cyclotron to bombard a film of plutonium-244 with calcium-48 atoms. Livermore supplied the plutonium-244, which is an exotic isotope that is difficult to manufacture. As part of the collaboration, Laboratory scientists also provided independent data analysis of the results. Since the team's discovery in December 1998, different isotopes of element 114 have been created, and other researchers have produced additional super-heavy elements—116 and 118.

Six R&D 100 Award Winners in 1999

Livermore scientists and engineers earned six R&D 100 Awards for outstanding achievement in research and



One of our 1999 R&D 100 Award winners is a much-improved power modulator for advanced accelerators, the first one based on solid-state components. Developed to improve radiography for stockpile stewardship applications, the modulator technology also helps to make feasible the Next Linear Collider, a next-generation high-energy particle accelerator.

development. Each year, *R&D Magazine* presents the awards to the top 100 industrial, high-technology inventions submitted to its competition. The Laboratory's award winners (listed on p. 30) will find applications in laser machining, communications, computer-chip manufacturing, cancer therapy, and law enforcement. They bring to 81 the number of R&D 100 Awards won by Livermore researchers.

SHAPING THE FUTURE

Positioning the Laboratory for the Future

In 1999, we faced major challenges both to our programs and to the way we operate. A number of important issues concerning Laboratory operations and programs arose during the year. They have required the special attention of management, who is working closely with DOE and the University of California toward their resolution. Actions we are taking today—together with our research accomplishments, planning activities, significant partnerships, and exceptional science and technology—position the Laboratory for the future.

Security and Safety Improvements

In 1999, our efforts to continuously improve Laboratory operations focused on security and safety. Recent events have reinforced the prime importance of security at the DOE nuclear weapons laboratories. We are taking specific actions to provide even greater protection of critical assets at Livermore, implement state-of-the-art computer security, and expand our counterintelligence program. We are also aggressively implementing DOE's Integrated Safety Management System to improve safety performance and management at Livermore. Our policy is that safety of both workers and the public has the highest priority.

When construction is completed, the National Ignition Facility will provide crucial support to the Stockpile Stewardship Program, make possible fusion ignition and burn experiments, and create opportunities to advance science in many areas through groundbreaking experiments.



A San Francisco Bay Area high school teacher learns how to rapidly grow crystals during one of the Laboratory's science education programs. She now conducts workshops for other teachers.



Congresswoman Ellen Tauscher frequently meets with technical staff to discuss national security issues as well as science education and advancement of women and minorities in technical fields.

Program Planning

The future direction of the Laboratory is guided by evolving national priorities. In addition to internal planning activities, we participate in significant planning efforts with our major sponsors. Livermore's priorities are spelled out in the strategy document, *Creating the Laboratory's Future*, and the *Laboratory's Institutional Plan FY 2000–2004*.

In addition, the Long-Range Strategy Project continued into its second and last year. The project—through the effort of about 20 of our early- to mid-career scientists and engineers—considered the potential advances in science and technology and prospects for Livermore over the next 10 to 20 years.

Major Partnerships for Mission Success

Increasingly, Livermore's technical achievements are the result of major partnerships with industry, academia, and other laboratories. Partnerships and collaborations help us accomplish our programmatic goals more efficiently and cost effectively. They also provide a mechanism for commercializing and returning for broad public benefit the technological advances made at the Laboratory.

Award-Winning Science and Technology

Outstanding scientific and technical achievements ultimately define the Laboratory and chart its future. Breakthrough accomplishments, critical to Livermore's success, are the product of a quality staff—both

individual and team efforts. Frequently such achievements lead to outside recognition, such as the many awards garnered in 1999.

A Quality Workforce

Livermore's principal asset is its quality workforce. Our achievements are the product of a highly talented, productive, motivated, flexible staff that is committed to the Laboratory's goals. We strive for a workforce that reflects the diversity of California and the nation. And we seek to provide a work environment in which all employees can contribute to their fullest and feel valued for their role.

Secure, Safe Operations and a Good Neighbor

Security and safety are the most important considerations in day-to-day operations. Protection of sensitive information, nuclear materials, and other valuable assets at the Laboratory is a critically important responsibility. So is safety. The Laboratory is committed to providing every employee and the community with a safe and healthy environment in which to work and live. We are implementing DOE's operational concept, Integrated Safety Management, to improve safety awareness and ensure that safety stays a top priority.

Environmental protection is also an important aspect of our operations and our commitment to being a good neighbor. We are making great strides in cleaning up the Livermore site. We broadly contribute to the high-tech, global-outlook atmosphere of the region. Our technical expertise, science education efforts, and the many volunteer activities by Laboratory employees are important parts of being a good neighbor.

Laboratory Improves Security Performance

Working closely with Secretary Richardson and other senior DOE managers, Livermore, Los Alamos, and Sandia national laboratories defined and expeditiously executed in 1999 a series of measures to tighten security. Protection of sensitive information and special nuclear materials at the laboratories is vitally important, and we are using increasingly sophisticated measures to provide it. All facets of our security triad—physical security, computer security, and counterintelligence—were thoroughly reviewed during the year. Steps are also being taken to implement tighter personnel security, including limited use of polygraph testing. Through new investments, revised procedures, and a greater security awareness by all

employees, the Laboratory has adjusted to new security threats and concerns and addressed identified weaknesses. In December 1999, each of the three laboratories was rated "satisfactory" in overall security performance—the highest on a three-tiered rating scale.

Integrated Safety Management Off to Good Start

Livermore is implementing DOE's Integrated Safety Management (ISM) System based on a set of work standards that were developed in partnership with DOE's Oakland Operations Office and the University of California. The Work Smart Standards were accepted, and ISM implementation began in August 1999. We have set a goal—safety performance comparable to the best of our peers—through top management leadership, clear definitions of responsibilities

An important resource for information safety, Livermore's Computer Security Technology Center provides response to breaches in computer security and develops advanced tools for actively managing and defending system security.

and performance expectations, and accountability. At Livermore, we have tended to focus our attention on special hazards associated with high-technology research projects. However, we can and must do better at preventing minor accidents connected with day-to-day activities.

Training in ISM was completed by all employees in September. Livermore's implementation of ISM is currently undergoing verification by DOE. In a two-week-long review of the first phase, in December 1999, the verification team noted a strong ISM commitment by senior managers and identified a number of noteworthy accomplishments.

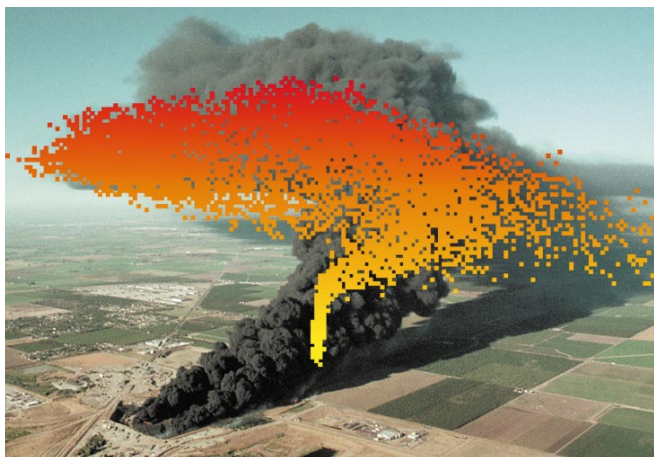
Groundwater Cleanup Way Ahead of Schedule

In July 1999, the Laboratory treated its billionth gallon of groundwater contaminated with chemical solvents. Ten years into the cleanup process, more than 425 kilograms of contaminant have been removed. We predict that the work can be completed almost 20 years ahead of schedule. Discarded solvents used in the 1940s while the site was a Naval Air Station and during early Laboratory operations seeped into the groundwater. A contaminated plume of groundwater stretching almost one-quarter mile beyond the Laboratory's perimeter was

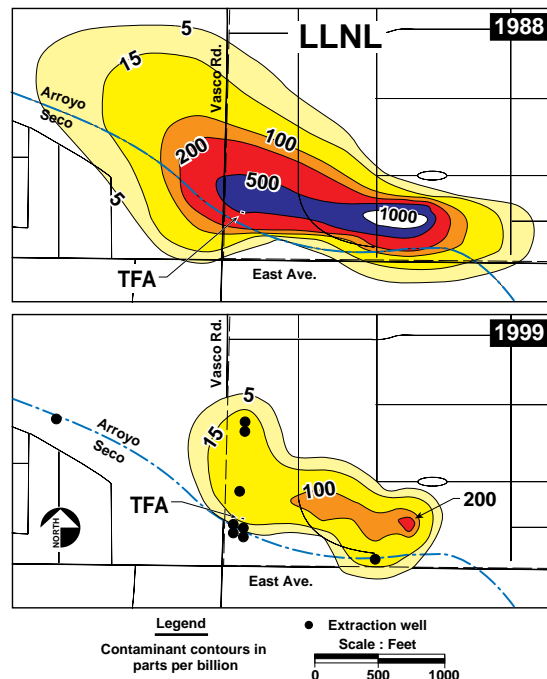
discovered in the 1980s. Although contamination was not a health risk to the surrounding community, cleanup began in 1989. Now the plume's outer edge in the shallowest water-bearing zone has been pulled back to within yards of the site boundary. Most of the contamination that remains is close to the regulatory limit.

Laboratory Employees Donate \$1.2 Million

The annual campaign to Help Others More Effectively (HOME) raised for Bay Area and Central Valley charity organizations \$1.2 million in 1999, breaking last year's record of \$1 million. HOME is but one example of many outreach activities that include employee participation in community economic development organizations; environmental, health, and safety working groups; and educational activities such as science fairs and student and teacher programs.



Livermore's Atmospheric Release Advisory Capability (ARAC) responds to atmospheric release emergencies worldwide. After a large fire began in a tire disposal pit near Tracy, California, we forecasted smoke dispersion and particulate concentrations in the Central Valley, thus helping California state agencies to alleviate the public's concerns about health effects.



A plume of contaminated groundwater that is beneath the Laboratory has been shrunk much faster than originally predicted using innovative solar-powered treatment units and fixed treatment facilities.

New Capabilities through Partnerships

Livermore's partnering activities span a wide range—from very-large-scale strategic alliances to licensing of individual technologies, academic research, and support for the small business community. Partnerships and collaborations often help us accomplish our programmatic goals more efficiently and cost effectively.

Technology Development with Industry

The Laboratory is acquiring mission-critical capabilities through major partnerships with U.S. industry, such as the Accelerated Strategic Computing Initiative and construction of the National Ignition Facility. We also enhance critical capabilities needed at the Laboratory for our national security mission through partnerships. In areas such as health care and environmental remediation, we "spin off" technologies for public benefit through cooperative research and development agreements (CRADAs) and licensing. Our many and varied interactions with U.S. industry are exemplified by Livermore's 98 active licensing agreements, 194 reported inventions, 105 patent

applications, and 76 issued patents in fiscal year 1999.

Improving Designs and Measurements for EUVL

Teamed together as a Virtual National Laboratory (VNL), researchers from the Lawrence Livermore, Sandia, and Lawrence Berkeley national laboratories are working with an industrial consortium to develop the next-generation technology for semiconductor manufacturing. We are pursuing extreme-ultraviolet lithography (EUVL) as a means for etching ultrathin patterns into silicon chips with a hundredfold performance improvement over those produced with today's technology. The research and development effort by the VNL is a \$250-million, multiyear CRADA partnership with the EUV LLC (Limited Liability Corporation) consortium consisting of Intel, AMD, Motorola, and Micron.

The VNL is currently focused on building and integrating the necessary technologies into an engineering test stand that will function as a prototype EUVL system. Livermore leads the efforts in the test stand's optical systems and components, thin films, masks, and submicrometer

The high-power solid-state green laser developed at the Laboratory has a variety of precision machining applications because of its exceptional performance and reliability compared with those of commercial copper-vapor lasers. It also can be used to pump ultrashort-pulse lasers, create laser displays, and treat disfiguring skin conditions such as port-wine stains. The technology won an R&D 100 Award.



The Ultra Clean Ion Beam Sputter Deposition System, developed at the Laboratory, is used to produce precise, uniform, highly reflective lithography masks. A key requirement of the next-generation lithography system is that it produce virtually defect-free masks. The system contributes fewer than 0.1 defect per square centimeter to each mask. The ultimate goal for extreme ultraviolet lithography is to add no more than 0.001 defect per square centimeter to a finished wafer blank.

metrology. In support of EUVL, further development of Livermore's precision deposition system won a 1999 R&D 100 Award. This year, shield design and other operational improvements were also made.

Optics teams are also working on advanced designs for projection optics, the optical heart of the lithographic exposure system. In addition, the Livermore metrology team is improving the capability to measure errors—from 0.35 to 0.15 nanometer—in the overall surface shape of aspherical optics.

PEREGRINE Goes Commercial

PEREGRINE, a revolutionary tool for analyzing and planning radiation treatment for cancer patients, will be appearing in hospitals within the next few years. Livermore has selected the NOMOS Corporation as a partner to transfer this unique system from the Laboratory into medical clinics. An R&D 100 Award winner in 1999, PEREGRINE will help a doctor

to plan radiation treatment on a patient-specific basis using a readily affordable PC-like machine. Compared with other dose calculation methods in current use, PEREGRINE can more exactly estimate the radiation being delivered to a tumor and nearby tissue because the modeling explicitly accounts for inhomogeneities in the body such as air, muscle, and bone that are identified on the patient's computed tomography (CT) scan.

Radar Technology Patents Upheld

After reexamination, the U.S. Patent and Trademark Office upheld all 20 original claims by the Laboratory in its patent for the micropower impulse radar technology, or MIR. The versatile technology has the potential for enabling a wide range of low-cost instrumentation, and the Laboratory has entered into 28 licensing agreements with companies that want to use MIR in applications.



Livermore and other DOE researchers are applying laser-based processing techniques to the production of plastic flat-panel displays. In this project for the Defense Advanced Research Projects Agency, thin-film transistors are applied to thin, flexible plastic sheets in a fabrication process that combines low-temperature deposition techniques with the use of ultraviolet pulsed beams so precise and fast that the plastic does not melt.

Award-Winning Science and Technology

1999 Gordon Bell Awards

At the Supercomputing '99 Conference, the Gordon Bell Award for best performance was presented to a team of researchers from Livermore, the University of Minnesota, and IBM. Laboratory recipients recognized for their application of high-performance computers to scientific and engineering problems included Bill Dannevik, Ron Cohen, Art Mirin, Bruce Curtis, Andris Dimits, Mark Duchaineau, Don Eliason, and Dan Schikore.

Livermore (represented by David Keyes) also shared a 1999 Gordon Bell Award "special" prize with Old Dominion University and NASA for a simulation that obtained an unprecedented level of performance on an unstructured grid application.

1999 R&D 100 Awards

Bob Stoddard and Ted Wieskamp for the Optical Modulator-Switch.

Muriel Ishikawa, Ronald Lougheed, Kenton Moody, Winifred Parker, Tzu-Fang Wang, and Lowell Wood for the Gamma Watermark.

Isaac Bass, Jim Chang, Curt Cochran, Ernest Dragon, Christopher Ebbers, and the U.S. Enrichment Corporation for the Diode-Pumped Solid-State Green Laser.

Craig Brooksby, George Caporaso, Roy Hanks, Steve Hawkins, Brad Hickman, Hugh Kirbie, Bryan Lee, Craig Ollis, Rob Saethre, and Bechtel for the Advanced Radiographic Machine modulator.

Jim Folta, Fred Grabner, Gary Heaton, Gary Howe, Richard Levesque, Claude Montcalm, Mark A. Schmidt, Eberhard Spiller, Stephen Vernon, Christopher Walton, Marco Wedowski, and George Wells for the Precision Deposition System.

Christine Hartmann Siantar, Paul Bergstrom, Bill Chandler, Lila Chase, Larry Cox, Tom Daly, Don Fujino, Dewey Garrett, Brian Guidry, Steve Hornstein, Ron House, Don Jong, Dave Knapp, Sarita May, Ed Moses, Ralph Patterson, Clark Powell, Jim Rathkopf, Alexis Schach von Wittenau, and Rosemary Walling for the PEREGRINE radiation dose calculation system.

Many Significant Honors and Awards in 1999

Michael Key, Stephen Libby, Kennedy Reed, and Peter Young were named fellows of the American Physical Society.

Jeff Wadsworth was named a fellow of the Minerals, Metals, and Materials Society.

Charles Landram was named a fellow of the American Society of Mechanical Engineers.

Michael MacCracken was named a fellow of the American Association for the Advancement of Science for leadership in modeling climate and air quality and coordinating international research activities.

Richard Post received the *Popular Mechanics* Design and Engineering Award for 2000 for his invention of a new type of bearing—a passive magnet bearing—which may last longer than ball bearings or other magnetic alternatives.

Scientists from Livermore and a Russian laboratory were honored by *Chemical & Engineering News* and *Popular Science* for their joint discovery of a new element, element 114, which lasted 30 seconds before breaking down into lighter elements.

The 1999 Hammer Award was presented to Livermore's Hazardous Materials Packaging and Transportation Safety Assurance Office (represented by Ron Natali), as part of a group of DOE contractors, the Suppliers Quality Information Group, that share supplier assessment information to save money. This annual award is given by Vice President Al Gore's National Partnership for Reinventing Government.

Jim Jackson received the DOE Don Ross Industrial Hygiene Award in recognition of exceptional service and contributions to industrial hygiene programs.

Fusion Power Associates Leadership Award went to Grant Logan for his contributions in accelerating the development of fusion.

Robin Newmark and Roger Aines received the Environmental Protection Agency's Outstanding Remediation Technology Award, with collaborators at the University of California at Berkeley and Southern California Edison, for work in dynamic underground stripping and hydrous pyrolysis/oxidation.

David Cooper was reappointed by President Clinton to the President's Information Technology Advisory Committee.

Charles A. McDonald Jr. was awarded the U.S. Strategic Command's Strategic Advisory Group Distinguished Public Service Award for "exceptionally superior civilian public service" in monitoring the safety and reliability of the nation's nuclear stockpile.

The board of directors of the National Registry of Radiation Protection Technology bestowed its emeritus status on Paula Trinoskey.

The Federal Laboratory Consortium Award for Excellence in Technology Transfer was given to Abraham Lee, Duncan Maitland, Luiz Da Silva, Dean Hadley, Christopher Lee, Pat Fitch, Dan Schumann, and Jim Sommercorn. The award was given to the laser-activated microgripper that releases a coil inside a cerebral aneurysm and greatly reduces the risk of a hemorrhagic stroke.

Darleane Hoffman, formerly head of Livermore's Seaborg Institute, received the 1999 Priestly Medal of the American Chemical Society for her work in the chemical properties of heavy elements.

Steve Gray received the Defense Intelligence Agency's Director's Award for Exceptional Leadership in setting up on a classified, secure network a Web site that combines up-to-date information on foreign proliferation with computational tools and models.

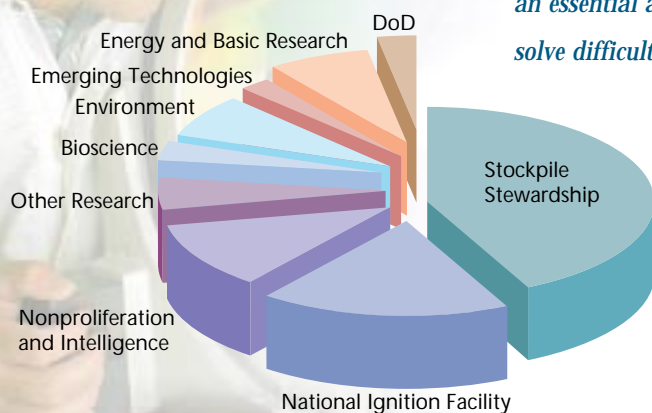
Steve Haan was named one of three 1999 recipients of the Edward Teller Award by the American Nuclear Society for his work in the design of inertial confinement fusion targets.

Jack Campbell received the 1999 Otto Shott Research Award of the European Society of Glass.

George Moorehead was named Livermore Chamber of Commerce's Helen Moody Volunteer of the Year.

About the Laboratory's People and Programs

Lawrence Livermore National Laboratory's principal asset is its quality workforce. Through a long association with the University of California, the Laboratory has been able to recruit a world-class workforce and sustain a tradition of scientific and technical excellence. With about 8,000 employees, Livermore has an essential and compelling core mission in national security and the capabilities to solve difficult, important problems.



FY 1999 Budget: \$1.36 Billion

A Quality Workforce

The Laboratory seeks a highly talented, productive, motivated, flexible staff that is committed to Livermore's goals and reflective of the diversity of California and the nation. We strive for a work environment in which all employees can contribute to their fullest and feel valued for their role.

The Laboratory's programmatic achievements would not be possible without the dedicated, high-quality efforts of all employees. The Laboratory greatly values the outstanding scientific and technical achievements of its scientific, technical, and administrative staffs. Their breakthrough accomplishments are critical to the success of Livermore's programs and provide the foundation for future programs to meet national needs.

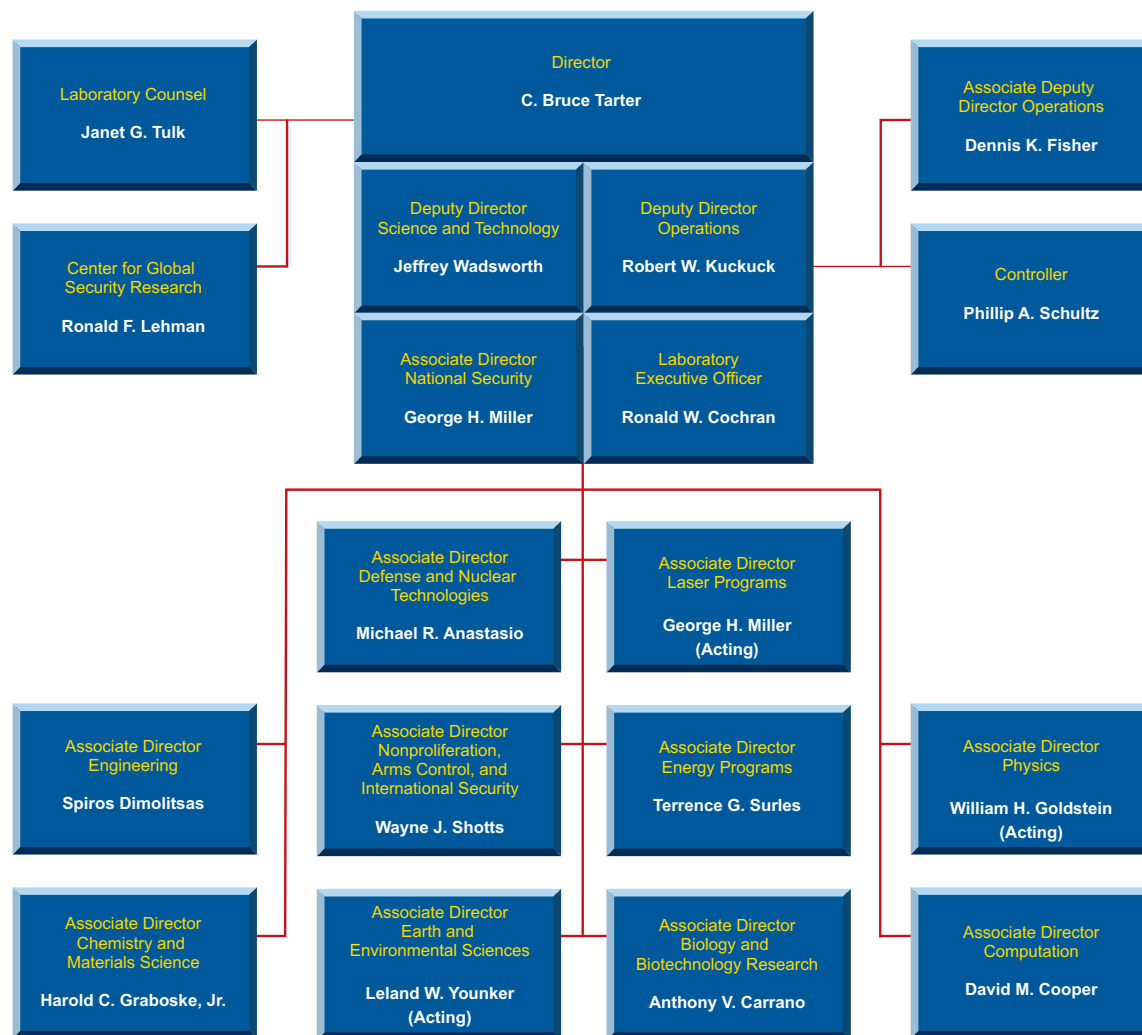
Laboratory Program Budget

Most of Livermore's \$1.36-billion budget for fiscal year 1999 was designated for research and development in program areas supporting the Department of Energy's missions.

As a national security laboratory, we are part of DOE's National Nuclear Security Administration (NNSA). We receive most of our funding from the NNSA Office of Defense Programs for stockpile stewardship. We also receive funding from the NNSA Office of Defense Nuclear Nonproliferation, various Department of Defense sponsors, and other federal agencies for national security work.

As a multi-program laboratory, we apply Livermore's special capabilities to meet important national needs. Activities are pursued for other DOE programs, principally Environmental Restoration and Waste Management,

Lawrence Livermore National Laboratory Organization



12/99

Fissile Material Disposition, Nuclear Energy, and Science. Non-DOE sponsors include federal agencies (such as the National Aeronautics and Space Administration, Nuclear Regulatory Commission, National Institutes of Health, and Environmental Protection Agency), State of California agencies, and industry.

Livermore Publications

Visit our Web site at <http://www.llnl.gov/> to learn more about our many scientific and technical programs and to

discover opportunities for employment, academic research, and industrial partnerships. Read about our accomplishments each month in *Science & Technology Review* on the Web or in print. Both *S&TR* and our *1998 Annual Report* were award winners in the Society of Technical Communication's 1999 international competition.

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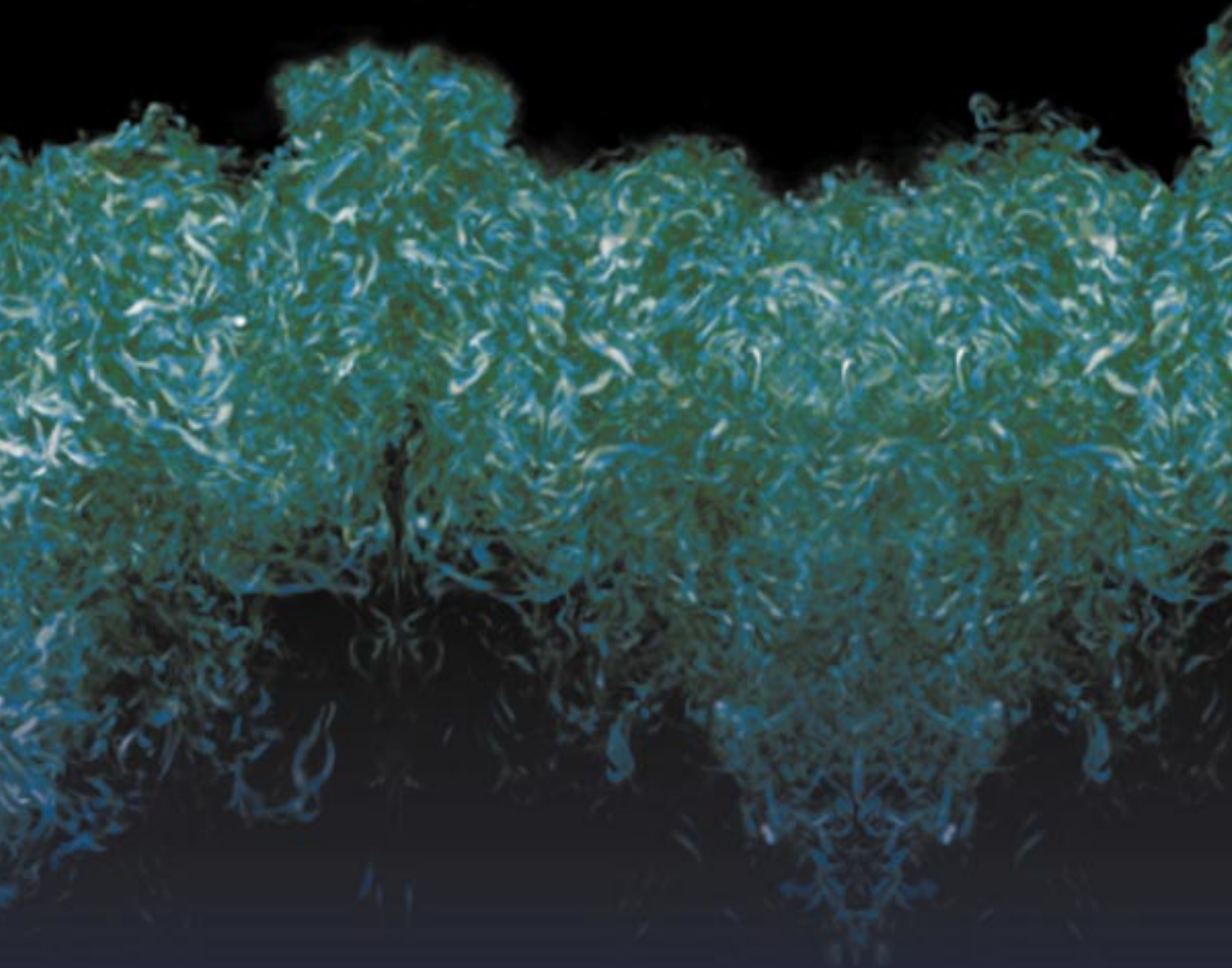
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High-Performance Scientific Computing at Livermore:

In a simulation (foreground) that won the 1999 Gordon Bell Award for Performance, the entropy (disorder) created by a shockwave passing through the interface between two fluids is calculated. The 8-billion-zone simulation took a week to run on an Accelerated Strategic Computing Initiative (ASCI) supercomputer at Livermore. Soon to arrive, the next, more powerful ASCI supercomputer (background) will be able to perform 10 trillion operations per second.